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VIRTUAL REALITY AND PROBLEM-BASED LEARNING IN STEM

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ABSTRACT

In the last decade, virtual reality (VR) has seen dramatic advances that have allowed VR technology to become integrated in business, education, and homes around the world. Immersive virtual reality (IVR) employs headsets and computer software to create an artificial environment containing three-dimensional images in which the user perceives full immersion. Individual virtual reality accessory devices allow the user to interact with the computer-generated environment and manipulate objects within the virtual setting. Immersive virtual reality is a mainstay in the gaming industry, with many new virtual reality games being released each month on multiple gaming systems. Gradually, the education research literature is accumulating evidence on the positive effects of the use of virtual reality technologies in educational settings with science, technology, engineering, and mathematics (STEM) disciplines and special education leading the way. Widespread usage of virtual reality in STEM must involve the development of readily accessible virtual reality subject-specific software and clear pedagogical plans and measurement systems designed to ensure fulfillment of virtual reality-based objectives (VROs) in the laboratory and classroom. A fusion of inquiry-focused learning strategies such as problem-based learning and virtual reality modules will improve virtual reality usage and student outcomes. Exploration of problem-based learning, potential uses, and limitations of virtual reality technology as well as the health hazards associated with integrating immersive virtual reality in STEM courses will be highlighted. The references provide a poignant starting point for interested educational researchers and STEM faculty.

KEYWORDS: virtual reality, pedagogy, problem-based learning, undergraduate, STEM.

INTRODUCTION:

Virtual reality systems have existed for several decades. The aviation industry and medical educators are fully aware of the immense advantages of immersive virtual reality simulations and have been employing this technology for many years (Moro, Štromberga, Raikos, & Stirling, 2017; Pfandler, Lazarovici, Stefan, Wucherer, & Weigl, 2017; Xin et al., 2018). However, it is within the last decade that virtual reality technology has seen substantive and rapid increases in development and application, fueled in part by potential benefits of this technology in business, academic, and government sectors. The virtual reality explosion on the societal landscape is also due to the overall reduction in costs and availability of portable VR systems and accessories. The increase in VR usage in educational settings is growing as educators realize the value of this cutting-edge technology. Pantelidis (2009) notes that "At every level of education, virtual reality has the potential to make a difference, to lead learners to discoveries, to motivate and encourage and excite. The learner can participate in the learning environment with a sense of presence, of being part of the environment." The terminology for virtual reality is diverse, complex, and often encompasses several different technologies. Virtual reality is defined as a computer-generated environment that affects multiple sensory stimuli. This article focuses on immersive virtual reality and will not emphasize studies and observations on mixed reality educational systems or augmented reality educational systems. This brief article provides an overview of virtual reality in general and offers a perspective into the potential use of this technology in undergraduate STEM classrooms.

Virtual reality technologies are impacting a variety of disciplines including education, history education, special education, and STEM areas (Beach & Wendt, 2015; Hutchison, 2018; Ludlow, 2015; Kaufmann, 2009; Kaufmann & Meyer, 2009; Yildirim, Elban, & Yildirim, 2018).

An increasing number of immersive virtual reality efficacy studies in a variety of STEM and STEM-related disciplines (e.g., medicine, nursing) are slowly appearing in literature databases (Kilmon, Brown, Ghosh, & Mikitiuk, 2010; Pfandler et al., 2017; Stepan et al., 2017; Weyhe, Uslar, Weyhe, Kaluschke, & Zachmann, 2018; Xin et al., 2018). In terms of medical schools, students regularly engage in virtual surgeries that allow students an opportunity to practice critical medical procedures on virtual patients without the need for human subjects or cadavers. These types of methods can be repeated an unlimited number of times without the costly cleanup and biohazardous waste removal procedures associated with clinical training.

Moreover, a number of studies demonstrated that immersive virtual reality educational systems enhanced student motivation (Huang, Backman, Backman, McGuire, & Moore, 2019), engagement (Makransky & Lilleholt, 2018), career aspirations (Weyhe et al., 2018), and comprehension of STEM-related content (Kaufmann, 2009; Markowitz, Laha, Perone, Pea, & Bailenson, 2018). Not surprisingly, some studies show that traditional pedagogical approaches (e.g., textbooks) are equally effective at promoting knowledge acquisition as immersive digital technology. Stepan et al. (2017) did not produce significant differences in students' anatomical knowledge following a randomized controlled investigation involving pre- and post-assessments. However, using the Instructional Materials Motivation Survey (IMMS) data demonstrated that learners in the experimental group perceived a higher level of engagement and enjoyment, and found the learning experience to be more useful for their future than the control group. Webster (2016) performed a mixed methods study to determine the capacity of IVR to improve participants' knowledge of essential corrosion prevention and control. Participants were randomly selected to either a lecture-based instruction group or an immersive VR-based multimedia instruction group. Following pre-test and post-test score analysis it was determined that both strategies were adequate, however, the IVR group produced more significant improvements in content knowledge.

Mayrose (2012) demonstrated that immersive environments were preferred over traditional pedagogical approaches to teaching physical science concepts and that student motivation was more significant for students who experienced the simulated three-dimensional environment. Parong and Mayer (2018) investigated to determine the efficacy of using immersive virtual reality versus a desktop slideshow to teach scientific concepts. The VR group show increased scores for motivation, interest, and engagement. The data also showed promise for using the generative learning model (GLM) when employing VR. Using GLM strategies, course content would be partitioned into individual learning units. Students would explore each learning unit using VR technology followed by opportunities to immediately reflect on academic content using a quiz, essay, or discussion. Domingo, Bradley, & Gates (2018) employed a qualitative approach to determine education students' perceptions of three-dimensional virtual reality in the classroom. The investigators found that students generally responded favorably to the use of VR. Participant responses also suggested that the students experienced meaningful social interactions and a reduction in social anxiety while using VR devices. The ability for immersive virtual environment technology (IVET) to alter cognition and behavior intention was observed in a recent study in which IVET was used to educate users on potential strategies regarding the conservation of water and the problems associated with noncompliance of water-conservation policies. Data revealed that the IVET experience significantly altered the thinking and potentially the behaviors of the participants regarding the advantages of conserving water (Hsu, Tseng, & Kang, 2018).

There are many benefits to incorporating virtual reality-based instruction that could allow students the opportunity to work and train in dangerous and hazardous environments without the risk of injury. For example, future nuclear engineers could receive training in a virtual environment before receiving training at a nuclear plant. Academic institutions could establish a tier-training system that first involves hands-on training in a safe virtual environment before exposing undergraduates to potentially life-threatening situations. Since virtual reality technology can recreate any environment, transporting STEM undergraduate students to remote locations, inhospitable habitats, dangerous biomedical laboratories, and research field stations are within reach. A distinct advantage of employing VR technology in the college classroom is the overall reduction in travel expenses and the elimination of threats to human welfare. Recently, Markowitz et al. (2018) performed a study in which over 270 research participants tested whether a virtual reality-based field trip could affect information procurement and query elaboration. Virtual reality software designed to replicate a marine

environment submerged students underwater to allow students to observe potential threats to the ocean floor and aquatic life caused by elevated acid levels in the sea. Analysis of pre-test and post-test knowledge valuations demonstrated a definite improvement in student understanding of the potential impact of climate change on ocean acidification. Access to cutting-edge training sites can be significantly mitigated using virtual reality synthetic environments. Increased exposure and access to previously impossible training opportunities have the potential to broaden participation in STEM education and careers among students with special needs and disabilities as well as impoverished minority populations and academic centers.

Health and Safety Issues:

Empirical findings indicate that some students experience unpleasant health-related complications while using virtual reality equipment (e.g., dizziness, nausea, headaches, migraines) (Jensen & Konradsen, 2018; Magaki & Vallance, 2017). Moreover, immersive virtual reality engagement has been shown to cause respiratory, intestinal, and mental problems during and after use. To ensure student safety while immersed in the VR environment science educators, clinical scientists, and physicians must collaborate to fully understand the health risks associated with VR use and develop inhibitory strategies to prevent student injury. Alternative academic activities must be provided for students who have preexisting health problems and concerns. In instances that require student movement in the virtual reality environment, adequate physical space must be provided to improve safety. The reduction of harmful physiological outcomes will significantly enhance the widespread use of virtual reality educational systems.

Problem-Based Learning:

It is hypothesized that college faculty will be able to produce meaningful educational outcomes for STEM students when virtual reality-based learning applications are coupled to established learning frameworks such as problem-based learning and constructivism (Huang, Rauch, & Liaw, 2010). Problem-based learning (PBL) is an effective pedagogical method that is designed to enhance critical thinking skills and problem-solving skills. Problem-based learning is a student-centered instructional method involving cooperative education, student projects, instructor facilitation, active learning, open-ended problems, presentation of conclusions, and student evaluation. In a problem-based learning course, student learning is focused on the completion of projects or experiments designed to investigate issues germane to a specific discipline (Barron, 1998). The inclusion of problem-based learning into the curriculum has been reported to have significant positive influences on college student academic outcomes and the development of higher-order thinking skills (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956).

Problem-based learning is based on substantial research on the effects of successful traditional instructional implementations that demonstrate its impact on content comprehension, development of communication skills, improvement of self-regulated learning skills, and overall competency in work-related skills (Ganesh & Smith, 2017; Overton & Randles, 2015). The tenets of problem-based learning are: a) producing learning-appropriate goals, b) providing supporting information to promote student learning, c) providing opportunities for student assessment and student evaluation, and d) providing opportunities for student collaboration and presentation of conclusions. Specific examples of how immersive virtual reality can be incorporated to achieve these educational objectives are also discussed. The overwhelming research base on PBL involves face-to-face teaching. This article suggests that the development of immersive virtual reality problem-based learning modules will lead to positive student outcomes that are greater than that observed when each strategy is examined individually.

Producing Learning-Appropriate Goals:

The role of the instructor in a problem-based learning course is to facilitate the learning experience. Facilitation involves designing a well-crafted problem, project, or experiment that allows students to learn crucial conceptual knowledge and learn relevant career skills (Barron, 1998). Also, at this stage in the problem-based learning model, the overall goal of the problem and explicit instructions must be clearly defined. Research indicates that learning is enhanced when the instructor incorporates a series of driving questions at different stages during the learning process. Specific questions ensure that in addition to learning essential methods or procedures, students also consider issues that elicit greater comprehension (Barron, 1998). Artificial worlds could be constructed to expose students to research and career environments in which specific problems and real-world issues could be explored to improve learning and occupation preparation efforts. For example, students could be relocated to a beach that has been devastated by an oil spill or natural disaster to use preexisting knowledge to design novel remediation efforts.

Providing Supporting Information to Promote Student Learning:

In this stage, the instructor provides additional coaching, instructions, and information to assist students in understanding the significance of conceptual knowledge to various applications in real-world settings. Supporting information also includes the presentation of research tools such as electronic research databases, journals, books, and research designs that support a students' ability to obtain more information about relevant procedures and essential content (Barron, 1998). In the virtual reality environment, students would have access to critical equipment, supplies, and other resources to test hypotheses and study the problem using the scientific method.

Providing Opportunities for Student Assessment and Student Evaluation:

This stage explores the use of formative assessment periods to actively determine the extent to which undergraduate students are assimilating critical information (Barron, 1998). Further, formative assessments regarding student understanding at various intervals in the process allow the instructor to reevaluate and alter educational interventions to ensure that learning-appropriate goals are being met. Student-instructor discussions can provide students an opportunity to present current conceptions and misconceptions and enhance student communication and evaluation skills (Barron, 1998). In this stage, students acquire the capacity to conduct self-analysis of comprehension and develop the intellectual curiosity to locate information to improve their understanding of conceptual knowledge. VR software mediating problem-based learning activities could be designed to allow for both formative and summative assessments. For example, students could have the opportunity to respond to questions in the virtual environment or complete questions following the virtual reality experience utilizing a group discussion in the classroom.

Providing Opportunities for Student Collaboration and Presentation of Conclusions:

Social interaction such as peer review activities, group presentations, and journal clubs are essential features of this stage of PBL initiatives. Research shows that collaborative experiences significantly enhance students' communication skills. Moreover, as a result of peer review activities students develop the ability to evaluate scholarly information (Barron, 1998). Clear and detailed guidelines must be established by the instructor regarding individual group member participation and expectations. In today's diverse workplace the demonstration of effective collaboration skills is essential. VR environments can allow for extensive STEM student collaboration. Many VR-based games have already mastered the technology of multi-player gaming, therefore designing STEM-based virtual reality experiences to enhance learning that involves multiple users working collaboratively to solve a specific problem would be relatively simple.

CONCLUSIONS:

Problem-based learning methods are common active learning strategies for STEM faculty. PBL strategies are a type of inquiry-based learning that helps students make connections between coursework and careers by presenting students with real-world societal issues typically in the form of open-ended questions. Students utilize preexisting conceptual knowledge and problem-solving skills to solve a problem. To implement PBL-related instructional tasks STEM faculty usually provide students with data or access to research equipment and supplies to collect data to address the main issue. PBL can involve an individual student or group interaction. The use of PBL-centered activities has been shown to lead to positive educational outcomes for STEM undergraduates (Overton & Randles, 2015). The incorporation of immersive virtual reality technology offers many promising benefits to improve STEM student engagement, retention, graduation rates, and occupational attainment. Virtual reality in STEM education is uncharted territory. Every STEM course and STEM student can potentially benefit from immersive digital environments. IVR could dramatically change the way STEM concepts are taught around the world. Typically, when compared to traditional teaching methods, VR learning activities are preferred over conventional environments. Data indicates that students are more motivated when engaging in virtual space as opposed to conventional brick-mortar classrooms and that educators are motivated to employ virtual reality in their classrooms (Domingo et al., 2018; Kavanagh, Luxton-Reilly, Wuensche, & Plimmer, 2017; Yildirim et al., 2018). Considering that many STEM concepts are abstract and require spatial recognition competencies, virtual reality environments could be constructed to more effectively inculcate ideas that have historically been difficult for the average student to understand. In a virtual reality problem-based learning environment, a computer-simulated environment that introduces students to potential societal issues and authentic STEM career challenges could be created. Students would use their accumulated knowledge, datasets, understanding of the scientific method, virtual scientific equipment, and other embedded resources to find solutions to carefully selected occupation-specific problems. Many different scenarios could be created in the virtual world that could edify the academic and professional development of a wide array of STEM students and disciplines at minimal costs to an undergraduate institution. Challenges to successful integration include overcoming safety hazards and deploying relevant VR pedagogical modules in STEM courses that enhance student outcomes (Kavanagh et al., 2017). Developing reliable methods or equipment to attenuate motion sickness and other adverse health problems must also be addressed to increase the use of virtual reality-based activities in undergraduate STEM classrooms and laboratories.

Additionally, training in the use and maintenance of VR systems is essential based on literary reports that technical difficulties play a role in teacher and preservice teacher acceptance. Overall, efficacy research on virtual reality in STEM is limited. Educational researchers should focus on the affective, cognitive, teaching, and learning issues associated with virtual reality use as well as undergraduate student outcomes related to virtual reality technology in educational settings. Quantitative and qualitative mixed methods research designs are important to thoroughly investigate the underlying issues that may enhance virtual reality education. Specifically, qualitative research designs offer significant

promise for IVR perception studies and IVR enhancement studies. The use of open-ended questions allows students and faculty opportunities to thoroughly articulate the advantages, disadvantages, and potential improvements in IVR educational settings. Qualitative software such as Nvivo (www.qsrinternational.com) can be used to identify themes that could prove useful for enhancing virtual reality software and virtual reality-based learning activities.

Elegant studies involving exquisite research designs such as randomized control trials are needed to resolve the efficacy of IVR in academic institutions further. The creation and identification of specialized VR STEM software will lead to reproducible best practices in the area of virtual reality-based pedagogical strategies. This article provides a seminal recommendation that virtual reality education and problem-based learning can and should be conflated to improve grades, reduce attrition in STEM courses, and ultimately enhance student progression toward advanced degrees in STEM and meaningful STEM careers.

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